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by

Tao Benren

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EXPERT SYSTEM FOR ANALYSIS AND DESCRIPTION OF EW ENVIRONMENT AROUND AN AIR DEFENSE SYSTEM

Tao Benren

Eighth Academy
China Aerospace Corporation
Shanghai 200233

ABSTRACT: To be the victor in combat, an air defense system must know the EW environment around it well. We need the expert system technology for analysis and description of EW environment around the air defense system because the EW environment is complex and more changeable. According to all jamming information in the air acquired from the EW environment reconnaissance system fixed near command center of the air defense system especially, the several radars in the air defense system, C^3I and so on. We can analyze the enemy's operational trends. Finally, we can make the optimal ECCM decision to the related weapon systems adaptively in the air defense system.

KEY WORDS: electronic warfare, air-defense, target recognition.

1. Introduction

Generally speaking, electronic warfare (hereafter referred

to as EW) is the prelude to modern warfare and therefore, it becomes a crucial requirement growing out of modern warfare in which the reconnaissance and analysis of the EW environment are performed by a air defense system in the pre-war period.

On the one hand, this strategy can be adopted to analyze enemy's combat operational intentions; on the other hand, it can be used, based on the actual jamming environment, to assist in decision-making in adapting various related weapons to the corresponding jamming countermeasures operations in the air defense system that will contribute to the maximum maintenance of the combat capability of the air defense system even in a severe jamming environment.

Therefore, the overall reconnaissance and accurate analysis of the EW environment around the air defense system can be a crucial precondition for the air defense system to gain a favorable position during the battle.

Basically, the fundamental task of reconnaissance of the electronic jamming environment on the battlefield is to roughly locate the various threat sources around the air defense system, and at the same time, to measure the relevant parameters from these threat sources so as to provide evidence for the battle operational decision-making purposes.

Yet it must be noted that the reconnaissance of electronic jamming signals differs from the reconnaissance of radar signals. Actually, the number of measurable parameters of electronic jamming signals appears to be smaller than for radar signals, which apparently will cause certain difficulties in the signal sorting process.

For an overall and accurate description of the electronic jamming environment, in many cases experience can be very

important in estimating some jamming parameters and conditions in aspects such as the distance of jamming source carrier, the judgment of he jamming strategy to be implemented by the jamming source carrier, judgment of the enemy's operational intentions and trends, and so on. All these factors should be analyzed and determined drawing on experience from actual battles; this can only be achieved through the expert system technology.

Thus, a knowledge database should be established in the first place for analyzing and describing the EW environment. Based on all the jamming source parameters measured with a special EW environment reconnaissance system as well as the experts' experience and knowledge provided in the database, a real-time analysis and description of the EW environment in the battlefield can be successfully implemented. As a result, enemy operational intentions and trends can be analyzed, and the optimal anti-jamming operation decision can be made for the related weapons to be included in the air defense system.

Notably, some factors such as the number of knowledge data in the database, logicality of the database structure, the determination of the reliability of the knowledge regularities, etc., will more or less affect the quality of the analysis and description of the EW environment in this expert system. Therefore, the design of this knowledge database will certainly play an essential part in making this entire system possible.

2. EW Environment Data

To perform the reconnaissance of the EW environment, an EW environment reconnaissance system is specially recommended to the command center of the air defense system or the C^3I command center. This reconnaissance system can be used to capture following data regarding the surrounding environment of the defense area:

* Number of omnidirectional active noise jamming sources in the air;
* Azimuth of each jamming source and its variation range;
* Frequency of each jamming source and its frequency and bandwidth variation range;
* Intensity of each jamming source and the intensity variation;
* Jamming pattern of each jamming source and its related parameters.

All of the above-mentioned information will then be renewed with each round of antenna scanning in the reconnaissance system providing a real-time monitoring over the surrounding EW environment.

In addition, some supplementary information can be obtained through other capabilities, such as information radar in the air defense system, target indication radar, and tracking guidance radar in the air defense system.

The information radar and target indication radar, apart from providing the supplementary information regarding the jamming sources with the corresponding frequency band, can also produce part of information pertinent to passive jamming in the air.

As far as the tracking guidance radar is concerned, it, prior to the battle, namely before the radar transmitter starts operation, can intercept the jamming sources one by one and measure the related data based on the indications of the jamming sources concerning tracking guidance radar frequency, which is provided by the reconnaissance system. While during the battle, i.e., after the radar transmitter starts operation, it can be used only for real-time monitoring over jamming sources at a certain high threat level. Overall, these radars can literally

furnish following data:

* Type, spatial range and variation of the passive jamming;
* Azimuth, pitch of jamming sources with the corresponding frequency band and their variation;
* Jamming pattern of the jamming sources with the corresponding frequency band and related parameters;
* Type of some deception jamming and related parameters;
* Jamming intensity of jamming sources with the corresponding frequency band and its variation rate.

Among other matters, some information can be alternately made available through other channels, such as the command center and adjacent defense regions. One should be aware that to be victorious in modern warfare, you cannot simply rely "solely" on a single weapon system. In principle, a combat pattern like a C^3I system should be implemented at least, that is to say, under a unified command from a command center and in collaboration with the adjacent troops, and only in this way can the victory of the battle be ensured.

Thus, the above-mentioned collaboration and mutual support cannot afford to be ignored in analyzing and describing the EW environment. The command center may provide some information from various channels as follows:

* Enemy combat operational scheme;
* Major static trend parameters;
* Attack direction, aircraft model, and number of targets;
* Jamming equipment carried by invading aircraft and related parameters;
* Weapon systems carried by invading aircraft.

Each adjacent defense region may also be able to furnish the related data parameters associated with the jamming source measured from its air defense system. These channels can

possibly provide even more complete information required in the analysis over the EW environment. Out of these data, some might not be able to be available only using the EW environment reconnaissance system as well as various radars in the air defense system. Again, obviously, the data acquired from the above mentioned channels can be vitally important in the analysis and description of the EW environment.

In summary, capturing all foregoing information regarding the EW environment in the battlefield can be made possible through the above mentioned three channels. While all of these data are just the ones that have been input into the knowledge database for the analysis and description of the EW environment.

3. Major Functions of Expert System

The major function of this expert system is to achieve following final results based on analysis and derivation over all of the data contained in the knowledge database.

* The estimation of the distance and position of various jamming source carriers in the air;
* The estimation of the tactic approaches to be carried out by various jamming source carriers in the air;
* The judgment of jamming patterns and related parameters of various jamming sources;
* Monitoring and tracking of the flight path of various jamming source carriers in the air;
* A comprehensive description of the EW environment in the entire air domain.

The above mentioned results are referred to as the output from this expert system.

4. The Basic Concept for the Knowledge Database

The major purpose of creating this knowledge database is to convert or describe, through combination, matching and derivation of all the data in the knowledge database, the results needed for understanding the EW environment. The criteria in the knowledge database will be established with different categories based on the features of the input information. Specifically, the input data will be sorted and classified through the following criteria set up in this database:

* Azimuth criterion (used to sort air domains);
* Frequency criterion (used to sort frequency domains);
* Pattern criterion (basically belongs to time domain sorting);
* Intensity criterion;
* Other criteria.

Each criterion includes a group of corresponding rule packages, and how to properly combine and arrange these criteria can be the primary concern of the quality of the database establishment.

Normally, we will first perform an initial positioning over various jamming source carriers in the air. At present, the EW environment reconnaissance system we applied can only produce the azimuth data for each jamming source in the air without the altitude data. Additionally, we cannot directly obtain the accurate distance data. Therefore, we have to perform an initial estimation over the rough distance of each jamming source through many other factors such as the jamming source intensity, its intensity variation rate and the jamming tactics performed by the jamming source carrier.

Then, based on the azimuth data and rough distance data of each jamming source, we can achieve initial positioning for each jamming source and perform a plane position display like the PPI display made by the target indication radar.

In principle, based on the time order of the input data in the knowledge database, some related rules are called for a judgment, followed by another judgment with the later data and using other related rules. And the previously-judged data will be verified and corrected, and each rule package is either independent or interrelated.

In some cases, the tactics employed by the jamming source will be determined first before going through the jamming source positioning process. The azimuth criterion, coupled with the intensity data, can be used to analyze whether this jamming source is long distance stand-off jamming (SOJ) or escort shield jamming (ESJ) or self support jamming (SSJ). In fact, the azimuth data are variable when SOJ fly in an ellipse way, and the azimuth data of the ESJ and SSJ are basically kept unchanged; both ESJ and SSJ will enter facing forward and therefore, show a larger variation in intensity. While in SOJ, the intensity variation is much weaker, from which fact the SOJ can be sorted out.

Then the ESJ and SSJ can be sorted based on the intensity criterion, frequency criterion or other criteria. Obviously, the jamming power of the ESJ is one order of magnitude stronger than that of the SSJ. Generally, ESJ flies over from a long distance away with a minor power variation rate, while SSJ, on the other hand, performs jamming in a near distance with a relatively large power variation. As a result, it is apparently not so difficult to distinguish SSJ.

Once the jamming tactics is determined, the flight speed and jammer power of the jamming source carrier can be derived using these determined data, and its distance then can be roughly calculated. Then, the SOJ and ESJ or SSJ can be sorted out using azimuth criterion.

For instance, suppose a jamming source carrier flies 50km in an elliptical manner at a speed of 200m/s, and this usually takes a time of approximately 4s. In this case, it will take a long time before making a judgment. As we all know, warfare is actually a competition of time, and therefore taking a long time to make a judgment can by no mean meet the actual warfare requirement. Under this circumstance, it is more logical for us to design a knowledge database based on the time order of data acquisition.

Nevertheless, since the derivation of some of the results is interrelated, for instance, the predication of the tactics application pattern must rely on the intensity or distance data as a robust evidence. While for the estimation of the distance, the data of tactics application pattern are needed as evidence.

This kind of interrelation will cause the first group of data coming into the database to have no immediate final results. Thus, we have to first give a rough estimation, which will not be further verified and adjusted until various data become growing. In other words, the acquisition of final results is a process of gradual refinement from level to level. The fundamental principle of constructing this database is shown in the schematic diagram in Fig. 1.

The input data will be sent to the knowledge database by the expert system for matching before an initial conclusion can be acquired. For instance, the jamming source azimuth, intensity, frequency, pattern, and so on are all first-coming data, which will be sent to the knowledge database for matching to obtain an initial conclusion. And then, based on the late-coming data such as intensity variation rate, azimuth variation, and so on, the first-level judgment will be corrected or verified through a in-depth judgment.

Because of the larger number of rules applied, this paper will not cover them one by one except for the positioning problem. The jamming equation (1) is utilized to set up the flight path of a jamming source which will be tracked.

$$P_r = P_j G_j G_r \lambda^2 \Delta f_r / (4\pi R)^2 \Delta F_j \qquad (1)$$

where P_r is reception power, P_j is transmission power of jammer, G_j is the gain of jamming antenna, G_r is the gain of reconnaissance receiving antenna, λ is the wavelength of jamming signal, Δf_r is the bandwidth of reconnaissance receiver, and ΔF_J is jamming bandwidth.

In the foregoing equation, all of the parameters of the reconnaissance receiver are known except for the transmission power of the jammer and the gain of jamming antenna. Therefore, a hypothesis can be made based on the initial results determined by the power-rule package.

Suppose the transmission power of the jammer is 1000W/Mhz, while the actual power is 2000W/Mhz, or 500W/Mhz, then a difference of 3dB occurs, and the corresponding distance will be different accordingly by 40%. In this case, there will be a large error in determining the rough position of the jamming carrier using the measured jamming intensity and intensity variation rate. But we can, based on this, establish the flight path of the jamming carrier and perform a tracking over the flight path. And this is virtually the main purpose of this system.

To obtain the actual location of the jamming carrier, the corresponding radar in the air defense system can be used to come up with a passive cross-positioning over the jamming source in the air to obtain its actual distance. This actual distance is then used to correct the rough distance determined by this system

and to move the flight path corresponding to that particular jamming source carrier on the integrated monitor to the actual location to enhance the positional accuracy. In some cases, indeed, the command center is also able to provide distance data of some jamming source carriers, which can also be considered in position correction.

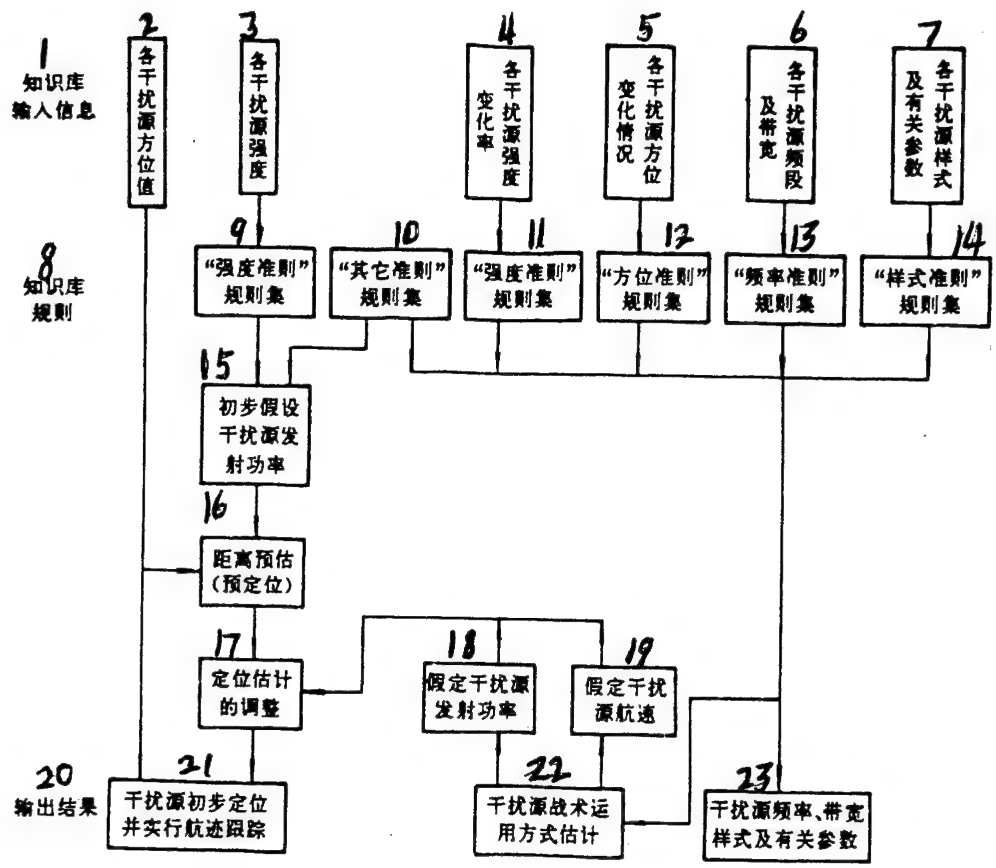

Fig. 1. Block diagram showing the fundamental concept of database establishment
KEY: 1. input data in the knowledge database 2. azimuth of various jamming sources 3. intensity of various jamming sources 4. intensity variation rate of various jamming sources 5. azimuth variation of various jamming sources 6. frequency band and bandwidth of various jamming sources 7. various jamming source patterns and related parameters 8. knowledge-database rules 9 "intensity criterion" rule package 10. "other criteria" rule package 11. "intensity criteria" rule package 12 "azimuth principle" rule package [KEY concluded on next page]

13. "frequency criterion" rule package 14. "pattern criterion" rule package 15. transmission power of jamming source based on initial assumption 16. distance estimation (pre-positioning) 17. adjustment of positioning estimation 18. assumed transmission power of jamming source 19. assumed flight speed of jamming source 20. output result 21. initial positioning of jamming source and flight path tracking 22. estimation of tactic application mode of jamming source 23. frequency, bandwidth and pattern as well as related parameters of jamming source

5. Expert System for Analyzing And Describing EW Environment

5.1 Hardware Configuration

This paper introduces a hardware system developed on the INTEL520. Generally, this system is multi-CPU system equipped with 20 plug-in slots. The bus structure is Multibus-II, coupled with a real-time operating system with the IRM x III.1 vision. And basically it is a real-time multi-task priority order system.

The number of CPU boards can be determined in the system configuration based on the jamming frequency band to be scouted by the air defense system. Principally, the data and signal at each jamming frequency band is configured with a CPU board for the processing purpose. As a result, the signal or data obtained in the reconnaissance system and radar with various frequency bands can be simultaneously sent to the corresponding CPU board for jamming pattern judgment and data processing. Then the data of jamming at various frequency bands, processed on various CPU boards can be sent to a CPU board running in the expert system through a bus for derivation and judgment process.

Based on the results judged by the expert system, on the one hand, the data obtained regarding all the jamming source carriers in the air will be listed in a table and displayed directly through the character terminal, and on the other hand, they will be sent for comprehensive graphic display.

Because the CPU board of the AT bus can also be inserted in the INTEL520 system, i.e., the PC subsystem, some operating systems such as DOS, Windows, etc., can also be run on this system, which can largely strengthen the capability of the system graphic display and interactive interface.

For this reason, the judged results from the expert system can, at the same time, be sent to the PC subsystem for reprocessing, and the results can be displayed using the comprehensive graphic display of the EW environment and various derivation results obtained from the expert system, and then a user-friendly interactive interface can be made possible. The system configuration is shown in Fig. 2. And the character display screen and comprehensive graphic display both can be renewed with each round of scanning of the antenna from the EW environment reconnaissance system.

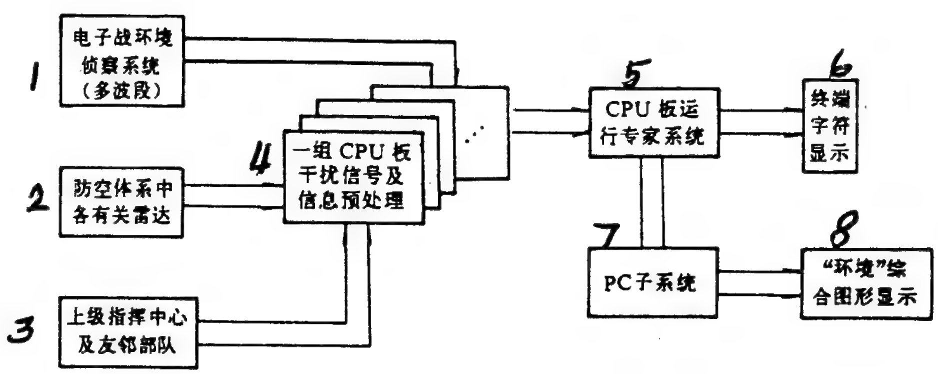

Fig. 2. Configuration block diagram of the system (on the right half of the Figure is expert system configuration)
KEY: 1. EW environment reconnaissance system (multi-band) 2. related radars in the air defense system 3. the command center and the adjacent troops 4. the jamming signals from a group of CPU boards and data preprocessing 5. the expert system run on the CPU board 6. terminal character display 7. PC subsystem 8. "environment" comprehensive graphic display

5.2. Makeup of expert system software

Structurally, this software system is an expert system coupled with a solution program constituted exclusively by the knowledge database featuring the EW and a unit which can capture and apply the knowledge. The structure of this software system is shown in Fig. 3.

In fact, this software package is a real-time multi-task knowledge database system specifically involving the task division among many CPU boards, data communication, etc. Thus, its structure is fairly complex and can be broken into five major modules according to different functions.

(1) Knowledge Database Module

This module contains the expert knowledge written with PROLOG language consists of two parts, rule database and derivation mechanism. Technically, the rule database can be randomly and continuously modified, expanded and optimized any time during actual battle application. While the derivation mechanism serves as a crucial part in the entire system, which is responsible for the call of the rule database as well as flow control of the entire system.

(2) PROLOG Language Environment Module

This module is a PROLOG compiling-interpretation system improved based on the FD-PROLOG system, which can generate a PROLOG language environment under any C-language-supported operating system, and it is equally a key component of this software system. This technology creates a favorable condition for the development of the expert system software on the INTEL520 system.

This module can achieve partial computation using an internal predicate, and it adopts the HASH technique (namely a conventional method of quickly searching for the data in the computer data structure, specifically through a certain HASH algorithm, reflecting the data searched to a given address in the computer so as to conveniently and quickly gain an access to this data) to look for special matched factors. This module can be made possible using C language.

(3) Display Module

This module features a jamming environment comprehensive display as well as the listing dynamic display of various related derived results for all of the jamming carriers in the air.

(4) Interpretation Mechanism Module

Generally speaking, the interpretation mechanism is executed under a non-real-time environment, which can track, log and derive the flow process allowing the user to clearly see the origin of the obtained results so that the experts and users can perform modification, addition and deletion over the rules generated from the expert knowledge. This mechanism proves to be a vitally important tool in terms of modification, addition, deletion and verification of the knowledge database.

(5) Communication Module

This module is responsible for the communication between a group of preprocessing CPU boards, PC subsystem and the CPU boards running in the expert system and, at the same time, take care of the coordination and synchronization among the multi-tasks.

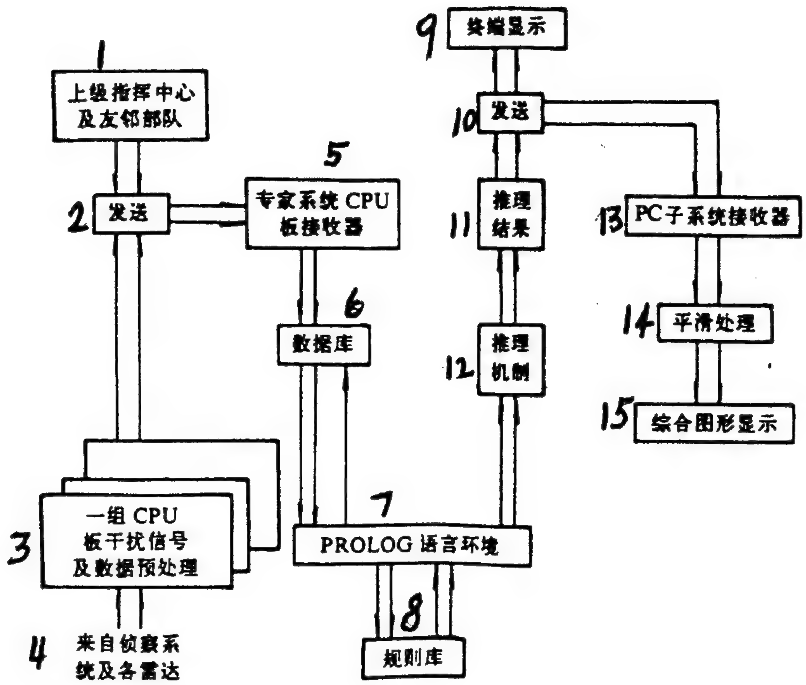

Fig. 3 Software system block diagram
KEY: 1. command center and adjacent troops 2. transmission 3. the jamming signals from a group of CPU boards and data preprocessing 4. from the reconnaissance system and various radars 5. the CPU board receiver in the expert system 6. database 7. PROLOG language environment 8. rule database 9. terminal display 10. transmission 11. derivation result 12. derivation mechanism 13. PC subsystem receiver 14. smoothing processing 15. comprehensive graphic display

5.3. Major features of the Software and its Technical Approaches

The major features of the software:

(1) Real-Time Capability

Since this system is designed to perform a complicated, multi-level, and multi-type derivation process over all of the

jamming sources in the air with each round of scanning of the antenna, it, thus, requires a strict real-time capability.

(2) Large Data Volume

This expert system has a capability of quickly accumulating the facts with each round of scanning of the antenna, which requires the system to be able to handle a great amount of data.

(3) Correlativity

The foregoing large amounts of data are interrelated, for instance, some of the jamming sources have different frequency bands, but they are likely to be emitted from the same carrier. Hence, they have to be correlated to the same carrier. In addition to the correlation feature of data, there is also correlation of knowledge. In fact, the formation of some final derivation results may need a judgment over different kinds of knowledge, which can inevitably result in the complexity of the results and derivation.

(4) Ambiguity

Also, most of the above-mentioned data have ambiguity to some extent. Still, the jamming signal itself tends to have random fluctuation which causes a poor data certainty. What is more, the positioning of jamming appears even more ambiguous. All these factors require this system to have a complicated and strict derivation system to ensure the derivational accuracy.

To meet the above-mentioned special requirements, the following technical approaches have been adopted in this system:

(1) The application of the HASH technique for quick matching over the facts. Since the data input into the expert system is

renewed regularly, and the data volume may have a limit in any case, thus, a HASH chart can be established in internal memory to store these data and also express these data with two-dimensional arrays. In other words, one dimension is the number of scanning rounds of the antenna, while the other dimension is the carrier batch number of data. In this case, the data obtained from one carrier within one round of scanning can be incorporated into a fact. In this way, the round number and batch number can then become a two-dimensional index number, which makes the search speed increase considerably.

(2) Breaking down facts and reducing invalid matching

Normally, the data from one jamming source consists of 12 items of parameters, and matching of one fact needs to call 12 items of matching function in order to be successful. Nevertheless, fact matching usually only requires five to six of their items. Therefore, based on different features of the rules in the knowledge database, i.e., different rules need different parameter items, it is necessary to break up the fact. In this way, different rules can be used to match the corresponding facts so as to reduce unnecessary cost on the whole.

(3) The compiling optimization of the arithmetic expression

PROLOG language is a kind of logical program design language, and the computation of arithmetical expressions can be equally executed with interpretation. In this event, the computation efficiency is unfavorably low. To overcome this, some of the computational formulas can be made possible using the functions of C language, and the types of the parameters in the formulas can, among other things, be fixed, and then they can be called in the form of internal predicates for the PROLOG derivation system. Basically, this approach is a compiling

optimization technique designed to enhance the computation efficiency.

(4) The circulating stack processing technique

Since a group of data can be provided after each round of scanning of the antenna of the reconnaissance system (the reconnaissance system equipped for this system can perform one round of scanning per second), and this operation will be run continuously to make the derivation mechanism stack and data stack constantly grow. As time passes, the facts will become expanded dramatically. In this case, the circulating stack approach can be applied, that is to say, an internal memory with a fixed length is initially assigned as a stack section. When the length of the stack exceeds the section, the bottom of the stack can be moved upwards, and the stack top data are put into the previous stack bottom similar to a circulating buffer zone. Essentially, this is a release of stack. Thus, the length of the stack section ought to be large enough to ensure a generous data volume needed for the derivation.

(5) Parallel control strategy

This system as a whole performs preprocessing and organizing as well as various judgments, analysis, and description for the input data and therefore, is a multi-task system. Hence, the 520 system with the multi-CPU can be utilized to perform parallel processing. The feature of the real-time multi-task operating system is to perform some tasks separately on various CPU boards; for instance, preprocessing and organizing data can be performed separately and simultaneously in a set of CPU boards at different frequency bands. Some of the tasks to be computed can be taken out of the derivation system and put into other locations. These approaches can increase the efficiency of the entire system.

(6) Highly effective ambiguity derivation technique

The Clark expression form based on ambiguity rules can be used to apply ambiguity derivation into each rule. Basically, the Clark method amounts to adding ambiguity parameters to the previous rules and to write the ambiguity derivation method directly into the rule. A reliability factor is set for each rule, which can be used as an evidence for the selection and application of the rules.

(7) Efficient jamming data processing technique

The input data from this system are all obtained through converting the randomly fluctuated jamming signals, and their stability appears to be very poor. This, in some way, may affect the accuracy of the derivation. Thus, we conducted data processing at every link of the process. For instance, a simple smooth processing was performed with the reconnaissance system software, and a wild point elimination and smooth processing was also done with a group of preprocessing CPU boards. Furthermore, smooth processing was done for both CPU boards run on the expert system and PC subsystem so that fairly smooth flight paths of jamming sources were derived.

Fig. 4 shows the comprehensive display result of the EW environment; on the right half of the figure are the to-be-determined parameters of various jamming sources received by the reconnaissance system; while on the left half are the flight paths of various jamming sources sent by the simulation data. Noticeably, the white square slip at the 0^0 azimuth is simulation chaff corridor. From this diagram, the military commander can envision a clear picture of the surrounding jamming condition in the defense zone, based on which, the enemy operational intentions and the threat levels of various jamming sources in the air can be analyzed and only then, can the optimal anti-

jamming operation decision can be made.

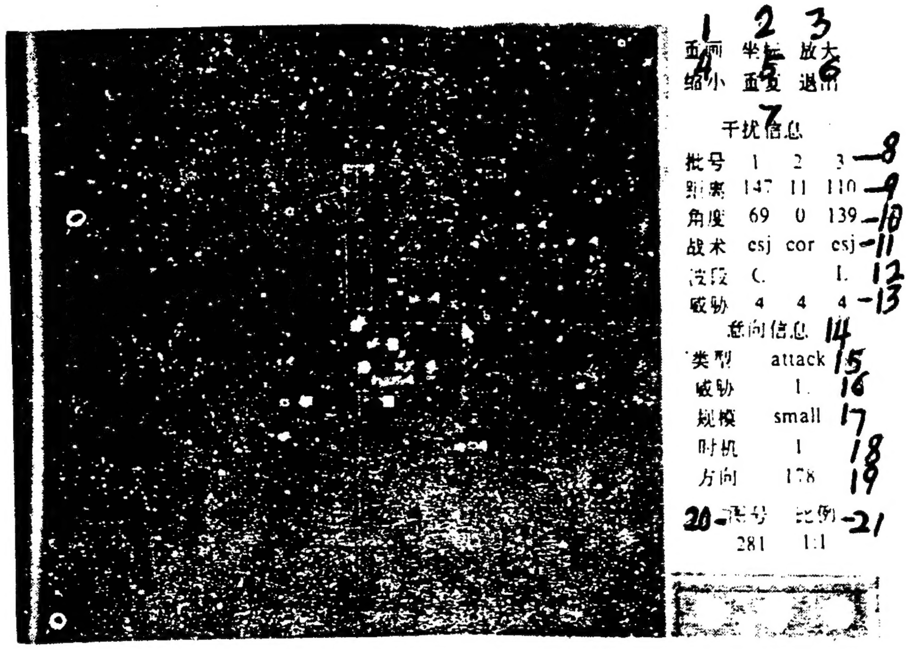

Fig. 4. Comprehensive display of EW environment (Note: each of the content items displayed in the "jamming data" on the right of the figure can be selected with a mouse.)

KEY: 1. redrawing 2. coordinates 3. zoom in
4. zoom out 5. repetition 6. quit
7. jamming data 8. batch number
9. distance 10. angle 11. tactics
12. waveband 13. threat 14. intention data
15. type 16 threat 17. scale 18. time chance
19. direction 20. diagram number 21. scale

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